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WINTER FINE PARTICULATE AIR QUALITY IN CRANBROOK, BRITISH COLUMBIA 1973 TO 1999

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Ministry of Water, Land and Air Protection
Pollution Prevention
Kootenay Region
Cranbrook, B.C.

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Cover photo: Looking east over residential, south Cranbrook – January 1987.

WINTER FINE PARTICULATE AIR QUALITY IN CRANBROOK, BRITISH COLUMBIA 1973 TO 1999

June 2001

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Pollution Prevention, Kootenay Region
Cranbrook, B.C.

Executive Summary

Airborne fine particulate matter is a cosmopolitan mixture of dust, pollen, smoke, soot and fine aerosols. The smallest of these particles (smoke and aerosols) can penetrate deep into the air sacs of the lungs and pose a serious threat to human health. A report released by the Ministry of Environment, Lands and Parks in 1995 estimated that in British Columbia fine particulate (PM_{10}) in outdoor air caused 148 hospitalizations and 82 premature deaths per year due to various lung and heart disorders.

Sources of PM_{10} in cities include smoke from industrial emissions, open burning and wood stoves, vehicle exhaust and windblown dust. Fine particles from combustion sources are a greater concern to human health than fine soil or dust particles. Communities located in mountain valleys in colder climates are subject to thermal inversions during the winter that prevents the upward dispersion of air pollutants. These conditions may persist for several days, allowing the PM_{10} to accumulate to levels considerably higher than would occur due to daily emissions.

Fine particulate monitoring began in Cranbrook in 1973 with a hi-volume sampler (hi-vol) on the roof of the old swimming pool and continued, with the exception of a few years in the early 1980's, until early 1999, when the pool was demolished. The monitor was re-established on the roof of the nearby Green Medical Clinic in early 2001. Hi-vols are operated for 24 hours every sixth day on the National Air Pollution Surveillance (NAPS) schedule. Prior to 1988 the hi-vol sampler collected all particle sizes (total suspended particulate or TSP), but was subsequently replaced by one fitted with a selective size inlet to capture only particles smaller than 10 µm (PM_{10}). By operating both the TSP and PM_{10} monitors side-by-side for two years in the early 1990's a mathematical relationship was produced and used to convert historical TSP measurements to PM_{10}. It was determined that only winter (November 1 to March 31) samples could be reliably converted in such a fashion, but this is the time of year when the highest levels of fine particulates occur.

Winter PM_{10} levels in Cranbrook increased from the early 1970's through to the early 1980's. In the winter of 1980/81 the average and maximum was 79 µg/m3 and 230 $\mu g/m^3$. By comparison, the average and maximum annual PM_{10} recorded in the Los Angeles area in 1999 was 72 $\mu g/m^3$ and 183 $\mu g/m^3$. Winter PM_{10} levels began to fall through the late 1980's and 1990's to average and maximum levels of 18 and 47 $\mu g/m^3$ in 1996/1997, the lowest on record. This represents a 77% and 79% decrease in average and maximum PM_{10} from the winter of 1980/81.

During the worst conditions, in 1980/81, 15 of 21 winter samples (71%) exceeded the current provincial PM_{10} air quality objective of 50 $\mu g/m^3$. In the five winters from 1994/95 to 1998/99 only 3 of the 109 samples (3%) exceeded this objective.

By the late 1990's annual PM_{10} air quality in the City of Cranbrook compared favourably with that of the surrounding countryside. Of all samples taken since January 1995 in Cranbrook, summer and winter, only 10 of 431 samples (2.3%) exceeded the 50 $\mu g/m^3$ provincial objective.

This compares, over the same period, with Johnson Lake, a rural site 45 km north of Cranbrook, where 4 of 486 samples (0.8%) exceeded the objective.

When historical patterns of fine particulate air pollution in Cranbrook are compared with known changes in industrial and mobile sources there is no apparent relationship. Three decades of observations and experience, plus research in similar communities throughout North America, have lead to the conclusion that the major source of PM_{10} in Cranbrook over this period has been the combustion of wood for home heating. While increased public awareness and the development of cleaner burning wood stoves may have been contributing factors to the improvements in winter air quality in Cranbrook, the most probable major cause was the progressive conversion from wood to natural gas fired appliances through the 1980's and 90's.

Unfortunately, the cost of natural gas has risen 115% in the last two years, again making wood an attractive alternative fuel. For this reason winter air quality in Cranbrook is predicted to deteriorate in the near future. The increase in cost of natural gas has been caused by a huge demand from thermal electric power plants in the United States, supplying electricity to a rapidly growing economy, dependent on digital equipment and the Internet, the latter doubling its electric power consumption every three months. If a resurgence of wood fuelled heating does cause winter air quality to deteriorate significantly, negative human health effects can be expected. This impact, a consequence of international natural gas markets and energy policy, will be greatest in small and medium sized communities in mountainous terrain, like Cranbrook, where wood supplies are still available.

Acknowledgements

The author would like to acknowledge the vital contribution of a group of individuals critical to the generation of this long-term data set – the field technicians who serviced the monitoring equipment over the past three decades. The dedication, perseverance and attention to detail of field personnel are often overlooked when environmental monitoring data is compiled and analyzed. Some of the staff that climbed up on roofs in all kinds of weather include: Allan Wong, Case Boskers, Steve Metzger, the late Robert E.G. Baker, Robert J. Davies, Loni Leinweber, Roland W. Grimm, Daniel P. Flegel, and, in particular, William P. Kusy, air quality technician from 1982 to 1996.

Thanks also to Suzana Prpic and Ron Colombo, of BC Gas Inc. for providing information on historical natural gas sales and supply in Cranbrook. Julia Beatty, Mark Strosher, Natalie Suzuki, and Paul Willis of the Ministry of Water, Land and Air Protection reviewed the draft report and provided comments and suggestions that much improved the final product.

Lastly, I would like to acknowledge Rick Crozier, Environment Assessment Section Head during the 1980's, who supported the re-establishment of the Swimming Pool monitor in 1985, and who promoted the operation of TSP and PM_{10} monitors side-by-side, which generated the data critical to this report.

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1.0 Introduction

Airborne fine particulate matter (FPM) is comprised of dust, pollen, smoke, soot and fine aerosols. Whether dense enough to form a visible haze or not, FPM has long been recognized as a chronic human health problem, particularly for persons suffering from pulmonary ailments such as asthma or emphysema. The seriousness of fine particulate air pollution was not widely recognized, however, until the publication of an article in the New England Journal of Medicine in 1993 which associated levels of FPM, previously considered safe, with excess human mortalities in certain U.S. cities (Dockery et.al. 1993). The findings of this study were given broad attention by the popular press (example: the Vancouver Sun, May 17, 1993). Prior to this publication air pollution reporting placed a greater emphasis on gaseous air pollutants, such as ozone and sulphur dioxide, mainly a concern in large urban centers, treating fine particulates as more of a nuisance (Cotton 1993).

In the early 1980's many smaller communities in colder climates were found to be suffering from very high levels of FPM. A major source of FPM (smoke) during the winter in some of these communities was wood stoves used for home heating. Poor emissions from large numbers of early air-tight models combined with thermal inversions in mountainous terrain allowed smoke to accumulate to levels which caused respiratory stress in some people.

In British Columbia emissions of FPM or other pollutants from large industrial point sources are and have been for over 30 years, regulated under the Waste Management Act. This has meant the development and installation of sophisticated control technologies that have greatly reduced pollutant contributions from industry. By contrast, individual emissions from the combustion of wood and fossil fuels for heating residential and commercial premises (i.e. chimneys) are exempted from the Waste Management Act, though a recent regulation, described later in this report, sets emission standards for new appliances sold.

Cranbrook is a city of approximately 20,000 population (BC Stats 1998) located at 915 meters above sea level in the Rocky Mountain Trench in south eastern British Columbia. The average annual precipitation (1968 - 1996) is 390 mm, approximately 40% of which falls as snow from October through March, and average monthly temperatures are 17.6° C in July and -8.0° C in January (Env. Can. 1996). Snow covers the ground typically from mid-November to mid-March each year. During winter the region often experiences intrusions of cold arctic air masses resulting in a pooling of cold air in valley bottoms. Under these atmospheric conditions the upward mixing of air pollutants, normally aided by rising air currents from surface heating, is limited. Valley inversions may persist over Cranbrook for several days or weeks before the arctic air is displaced eastward by low-pressure systems from the west. Under inversion conditions air pollutants accumulate over the city producing much higher ambient concentrations than would result solely from daily emissions.

This report presents the results of winter FPM monitoring in Cranbrook from 1973 to early 1999 and attempts to explain the indicated trends using local observations and knowledge and published reports of the experiences of other North American locations over this period. Annual

FPM levels in Cranbrook during the 1990's are compared with those from a rural site and against current air quality guidelines. Finally, some predictions for future FPM air quality are made.

2.0 Health Effects of Fine Particulate Matter

(This section has been taken largely from Vedal, 1995, except where otherwise cited)

Particles of FPM in air may range in size from 0.005 μm to 40 μm (CEPA/FPAC 1999) but the particles smaller than 10 micrometers (μm) in diameter can be inhaled into the lungs. In the 1980's FPM monitoring instruments were developed to sample particles smaller than 10 μm, referred to as PM_{10}. Prior to this, FPM monitoring captured all particle sizes and was referred to as total suspended particulate or TSP. The latest generation of monitors samples particles smaller than 2.5 μm ($PM_{2.5}$).

The smaller the particle, the deeper into the lungs it can penetrate and $PM_{2.5}$ is sometimes referred to as "respirable particles" because these particles reach deep into the alveoli of the lungs. This is the particle size range of greatest concern to human health and is comprised mainly of combustion by-products (smoke) (CEPA/FPAC 1999). Contemporary scientific literature is increasingly referring to the size fraction from 2.5 μm to 10 μm as "coarse particulate" and those particles less than 2.5 μm as the "fine particulates" (CEPA/FPAC 1999, SCAQMD 2000, Vedal 1997). For the purposes of this report, fine particulate matter (FPM) refers to PM_{10}, which includes $PM_{2.5}$. The "coarse" fraction may include significant portions of windblown dust whereas $PM_{2.5}$ does not. The crustal or soil-derived coarse particles that contribute to PM_{10}, particularly in the summer, are not associated with increases in respiratory disease (CEPA/FPAC 1999). The fine fraction or $PM_{2.5}$ has a stronger association with mortality, hospitalisations, and pulmonary symptoms than measures including the coarse fraction, i.e. PM_{10}, (CEPA/FPAC 1999) and selective particulate monitoring for $PM_{2.5}$ is thus becoming more common.

The health effects associated with FPM range often begin with irritation of the upper respiratory tract (sore throat, congestion), and/or the lower respiratory tract (shortness of breath, wheezing, chest tightness). The outcome can range from restricted activity, and absenteeism, to hospitalization and premature death. Vedal (1995) estimated that increases in PM_{10} cause 82 extra deaths in BC each year, 24 from lung disease, 27 from heart disease. He also estimated that PM_{10} pollution causes 69 extra hospitalizations for lung disorders, 60 for heart disorders and 17 for asthma.

FPM is always present in low concentrations in outdoor air. Estimating the risk to human health from FPM requires some information on the exposure of a population to levels in excess of background. Vedal (1995) proposed the concept of PM_{10} "health increments" as a means of estimating the acute impact of daily PM_{10} on an exposed population. One "increment" being equivalent to each 10 $\mu g/m^3$ increase in PM_{10} above a background or reference level of 20 $\mu g/m^3$, based on daily average levels, typically measured with the hi-volume sampler. This approach accounts for both the frequency of elevated PM_{10} levels as well as the intensity of each episode. For example, 3 days of PM_{10} between 30 and 40 $\mu g/m^3$ would be equivalent to 3 increments, as would one day with a level between 50 and 60 $\mu g/m^3$. A day with PM_{10} less than 30 $\mu g/m^3$ is not

counted. The "health increment" (HI) method of estimating the potential health effects of exposure to fine particulate air pollution in Cranbrook over the years has been used in this report.

3.0 History of Fine Particulate Monitoring in Cranbrook

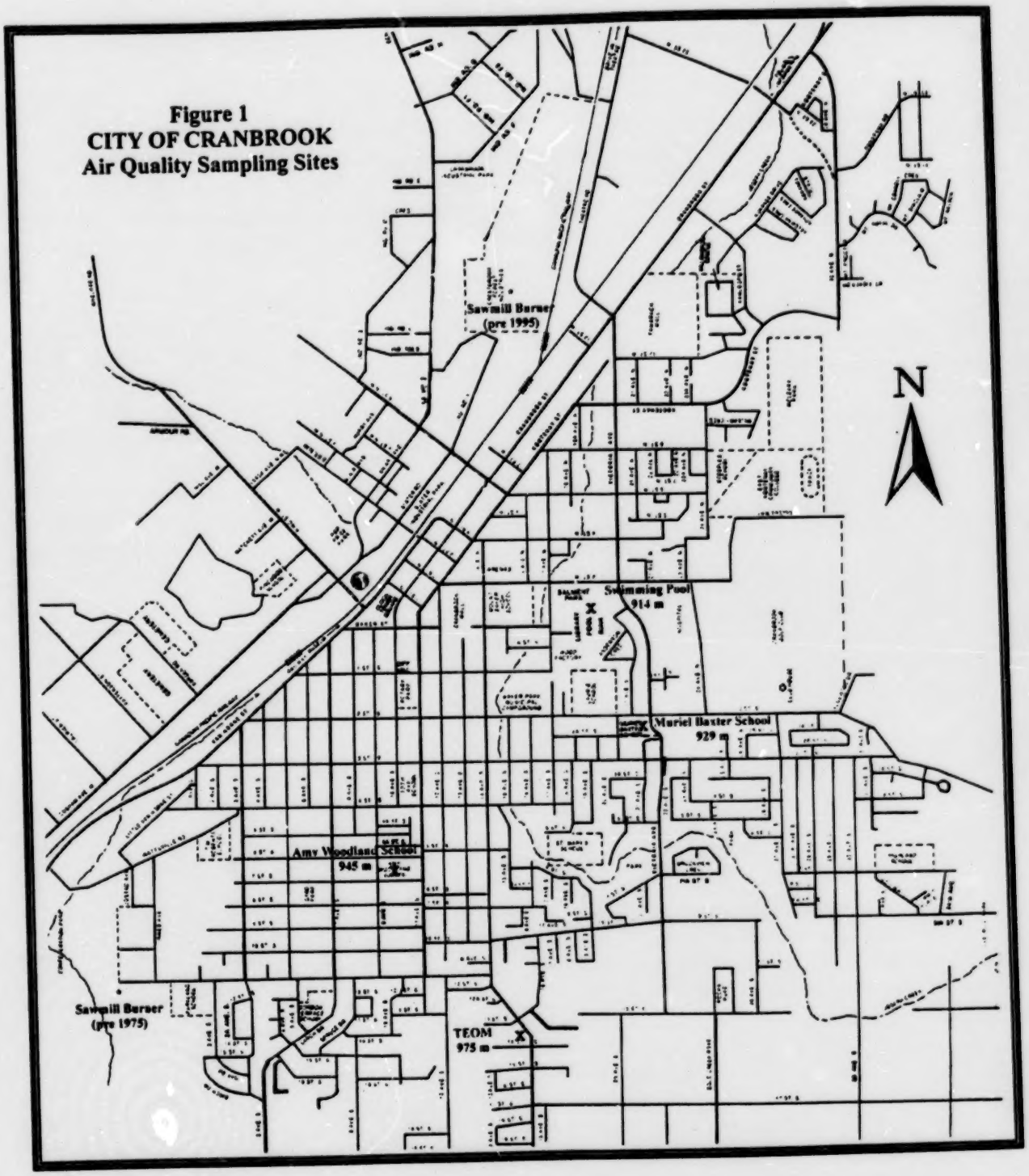
Through the 1970s the Ministry of Environment conducted a major environmental study throughout the south-eastern portion of the province. The Kootenay Air and Water Quality Study, based on 8 years of extensive monitoring, reported on the state of the environment in the south-eastern portion of B.C., in relation to major industrial and municipal waste discharges and emissions. As part of this study a hi-volume sampler or hi-vol, which sampled total suspended particulate (TSP), was located on the roof of the Cranbrook swimming pool (CSP), where it operated from 1973 to 1981 (Figure 1). Monitoring was terminated at this point as part of a network reduction but was initiated again in 1985 due to observations of poor air quality by local Waste Management Branch staff and an increase in the number of complaints from the public. It is the data from this monitoring site, spanning nearly 26 years, which have been analyzed in this report.

The hi-vol sampler is comprised of a vacuum cleaner motor, operating on a timer for 24 hours, drawing a known volume of air through a 20.3 x 25.4 cm glass fiber filter which retains particles larger than 0.3 μm in diameter. The filter is pre-conditioned at 20 ± 3 °C and 45 ± 5 % humidity and accurately weighed before and after sampling. The difference in these weights and the total volume of air sampled are used to calculate the particulate concentration over the 24 hour sample period, expressed as micrograms per cubic meter ($\mu g/m^3$). Hi-vols are normally operated every 6 days on a schedule established each year by Environment Canada called the National Air Pollution Surveillance or NAPS schedule. This stratified sampling system produces about 60 samples per year, repeatedly covering each day of the week.

TSP hi-vols merely have a gabled aluminium roof covering the filter to shield it from precipitation and dustfall. PM_{10} hi-vols are fitted with a size-selective inlet consisting of a large round aluminium housing containing an impacting chamber where particles larger than 10 μm impact and stick to a greased collection plate. Smaller particles continue with the airflow over the impacting plate to be collected on the filter.

In 1986, TSP hi-vols were also set up at three other locations, two in other parts of the city (Amy Woodland and Muriel Baxter schools) and one in a rural location (near Fort Steele), which served as a reference site (Crozier and Manna 1988). Monitoring locations within the City of Cranbrook are shown on Figure 1. These additional sites were established to determine the variability in FPM levels throughout the city, compared with those at the CSP site. Additional monitoring equipment installed at Amy Woodland School included a dichotomous sampler, to measure two size fractions of FPM, a polyurethane foam or PUF sampler to measure polycyclic aromatic hydrocarbon compounds (PAHs) and a PM_{10} hi-vol. All these data were reported in Crozier and Manna (1988). The PM_{10} hi-vols at the CSP and Amy Woodland were operated simultaneously beside TSP hi-vols in order to establish a mathematical relationship between

Figure 1
CITY OF CRANBROOK
Air Quality Sampling Sites



PM_{10} and TSP. This relationship has been used in this report to convert historical TSP to PM_{10}. By 1988, all hi-vols were converted to PM_{10}, and in 1991 the additional sites were shut down, leaving only the PM_{10} hi-vol at the CSP.

In 1989 a continuous monitor was also installed at the CSP to support a program of winter air quality advisories. The instrument, called a nephelometer, measured the amount of light back-scattered by FPM in outdoor air as it passed through a detector. Twenty-four hour average output from the nephelometer was correlated with same day PM_{10} hi-vol samples in order to estimate the daily average PM_{10} levels used for the air quality advisory.

In 1992 the nephelometer at the pool was replaced with a tapered element oscillating microbalance or TEOM™, one of the first in the province. This instrument produced instantaneous PM_{10} measurements as well as hourly and daily averages. Following initial technical problems, staff became concerned that the TEOM™ intake, located on the north-east corner of the swimming pool roof, was occasionally sampling exhaust air from the building ventilation exhaust vent (the hi-vol had always been situated in the north-west corner and not affected by this vent). In 1993 the TEOM™ was moved to a building housing a water main valve, called PR3, in a residential part of town, 2.3 km south of the CSP and 61 meters higher in elevation (Figure 1). A location nearer the town center would have been more representative of city-wide air quality but PR3 was the only available facility satisfying the rigorous TEOM siting requirements.

In 1998, due to a lack of operating funds, the TEOM™ was removed and relocated to Golden. The PM_{10} hi-vol at the pool continued to operate until March 1999 when the swimming pool building was demolished and construction of a new recreation complex begun. The PM_{10} hi-vol has now (March 2001) been relocated to the roof of the Green Clinic, approximately 400 meters southwest of the former CSP site.

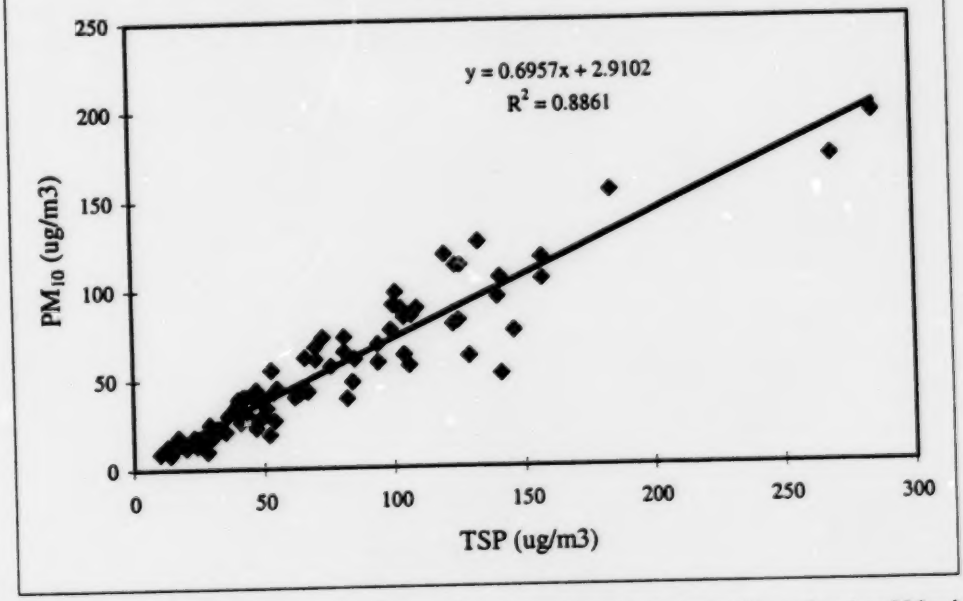
4.0 Data Analysis

4.1 Conversion of Winter TSP to PM_{10}

In order to examine the entire 25-year period of record from the CSP site it is necessary to convert older TSP monitoring data to PM_{10}. This conversion has been done using an empirical relationship between side-by-side pairs of TSP/PM_{10} samples, taken over 2-3 years. Only winter (November 1 to March 31) samples have been included in this analysis for two reasons. First, with the exception of occasional forest fires, the highest levels of combustion source FPM (smoke) occur in winter, so this is the time of year of greatest concern for human health. Second, winter particulate is mainly comprised of wood smoke and street dust but, because of snow cover, does not include other area dust sources, like baseball diamonds, gravel parking lots, and pollen that can be significant in the summer. Particles from these latter sources that are larger than 10 microns are excluded from PM_{10} samples, resulting in a different TSP/PM_{10} relationship in summer than winter (CEPA/FPAC 1999). Coarse summer particulate levels vary from year to year, depending on weather conditions, potentially masking trends in PM_{10} and the TSP/PM_{10}

relationship. Using only winter samples reduces the influence of these non-combustion particles, of less concern to human health, and produces a more reliable TSP/ PM_{10} relationship for converting historical data.

Figure 2. Regression of Winter PM_{10} on Total Suspended Particulate from Amy Woodland School (1985 - 1991)



Based on 84 pairs of simultaneous, side-by-side hi-vol samples taken between November 1 and March 31, each winter from 1986 to 1991.

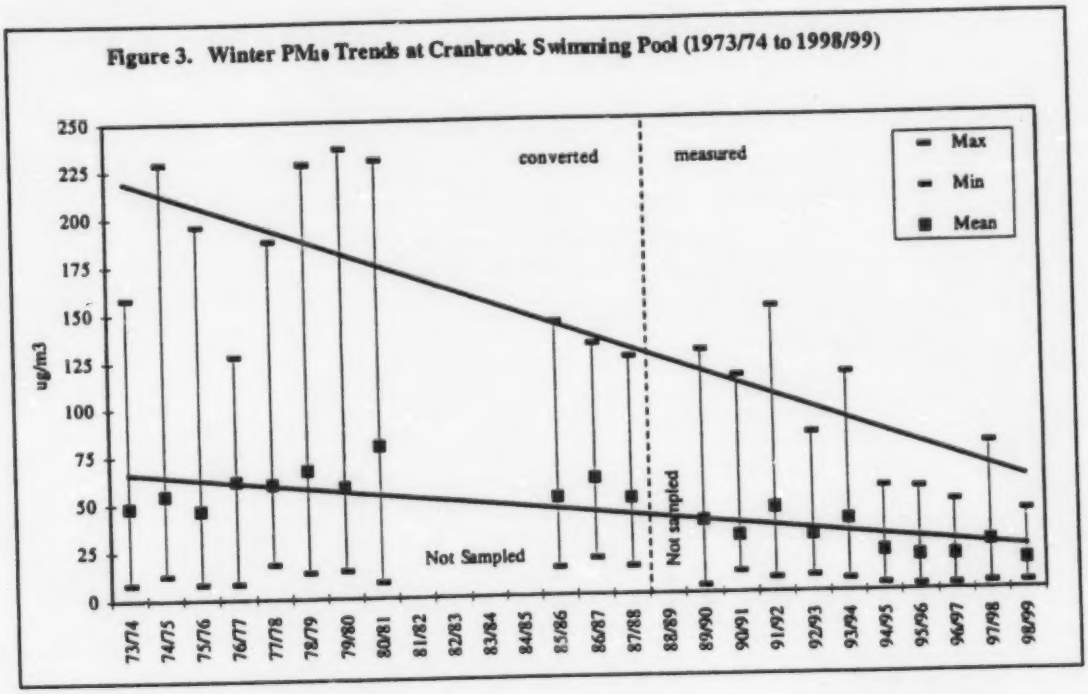
Ideally, to convert historical TSP data to PM_{10} at a given site, a TSP/PM_{10} relationship developed from samples gathered at that site should be used. Unfortunately only 14 pairs of these samples were collected during one winter (1990/91) at the CSP site, including a maximum PM_{10} of only 56 $\mu g/m^3$. At Amy Woodland School (AWS) 84 pairs of TSP and PM_{10} samples were collected through the winters of 1985 through 1991, including two PM_{10} samples greater than 150 $\mu g/m^3$ (Figure 2). AWS is located 1.3 km south west of the CSP, 31 meters higher in elevation, and is located in a residential area (Figure 1).

Using the regression from the AWS site to convert historical TSP from the CSP site obviously introduces a measure of uncertainty. This potential error is lower if the results from the two sites sampled on the same day are similar. A comparison of 17 same-day PM_{10} samples from AWS and CSP during the winter of 1990/91, and 80 pairs of TSP samples during four winters from 1986 to 1991, were not significantly different (student's t test, $p = 0.01$). It is therefore reasonable to conclude that the potential error using a TSP/PM_{10} relationship developed from AWS will be less than using one from the CSP based on a much smaller sample size and lacking in higher range values.

4.2 Winter Fine Particulate in Cranbrook 1973/74 to 1998/99

Winter PM_{10} data from the CSP, both converted (1973/74 to 1987/88) and measured (1988/98 to 1998/99), are listed in Appendix I. Figure 3 illustrates the trends in maximum, minimum and mean winter PM_{10} over this period. Only NAPS samples have been used in this graph, excluding

Figure 3. Winter PM_{10} Trends at Cranbrook Swimming Pool (1973/74 to 1998/99)

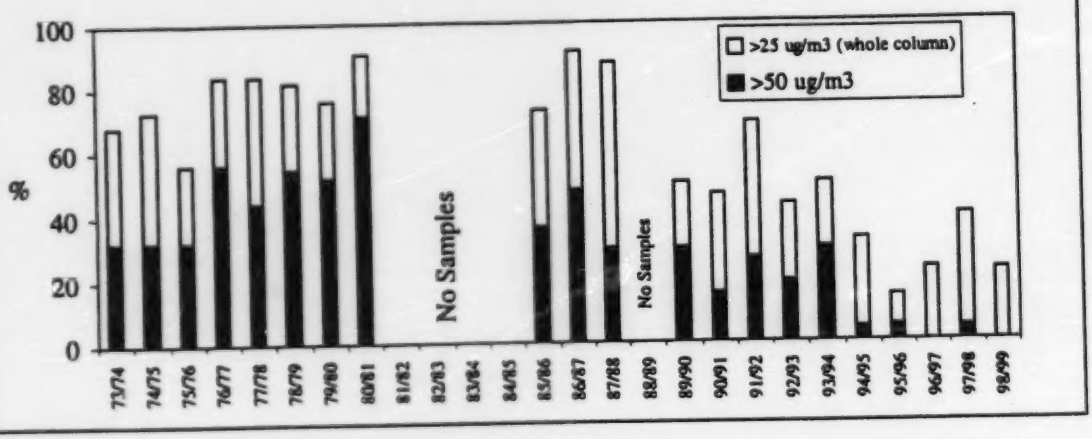


other samples that were occasionally taken, which would introduce year-to-year bias. The linear regression lines on Figure 3 have been inserted to illustrate the downward trend in annual mean PM_{10} (lower line) and annual maximum PM_{10} (upper line) over the three decades.

Winter PM_{10} averages ranged around 50 $\mu g/m^3$ through the mid-1970's, rising to 79 $\mu g/m^3$ in the winter of 1980/81. Through the 1980's and 90's winter averages steadily decreased to 15 $\mu g/m^3$ in the winter of 1998/99. Winter maximums followed a similar pattern, the highest, 236 $\mu g/m^3$, recorded in the winter of 1979/80 (converted from a TSP sample of 335 $\mu g/m^3$). To help put these FPM levels in Cranbrook in context, the maximum and annual average PM_{10} recorded from a 37 station monitoring network in the Los Angeles area in 1999, employing the same methods, was 183 $\mu g/m^3$ and 72.3 $\mu g/m^3$ (SCAQMD 2000). It must be stressed that this is a comparison of 151 days of winter exposure (November 1 to March 31) in Cranbrook during the early 1980's with current year around, 365 day exposure in Los Angeles.

Appendix I also lists the number of samples each winter that exceeded both the current 24-hour PM_{10} air quality objective for B.C. of 50 $\mu g/m^3$ and the National PM_{10} reference level of 25 $\mu g/m^3$ (CEPA/FPAC 1998). Reference Levels are defined as "levels above which effects on human health and the environment can be demonstrated" (CEPA/FPAC 1998). These data are graphed in Figure 4 and show that the number of NAPS samples that exceeded the provincial objective (50 $\mu g/m^3$) increased from about 30% in the early 1970's to 70% in the winter of 1980/81. That winter, 15 out of 21 samples (71%) were greater than 50 $\mu g/m^3$, the worst winter FPM air quality over the past three decades of monitoring. From 1976 to 1981, most of the winter NAPS samples were greater than 25 $\mu g/m^3$ (56 to 90%), in fact over those five winters only 2 to 6 samples per winter were below this value. When sampling resumed in the winter of 1985/86, the number of excursions over 50 $\mu g/m^3$ had decreased to early 1970's levels (8 of 22 samples or

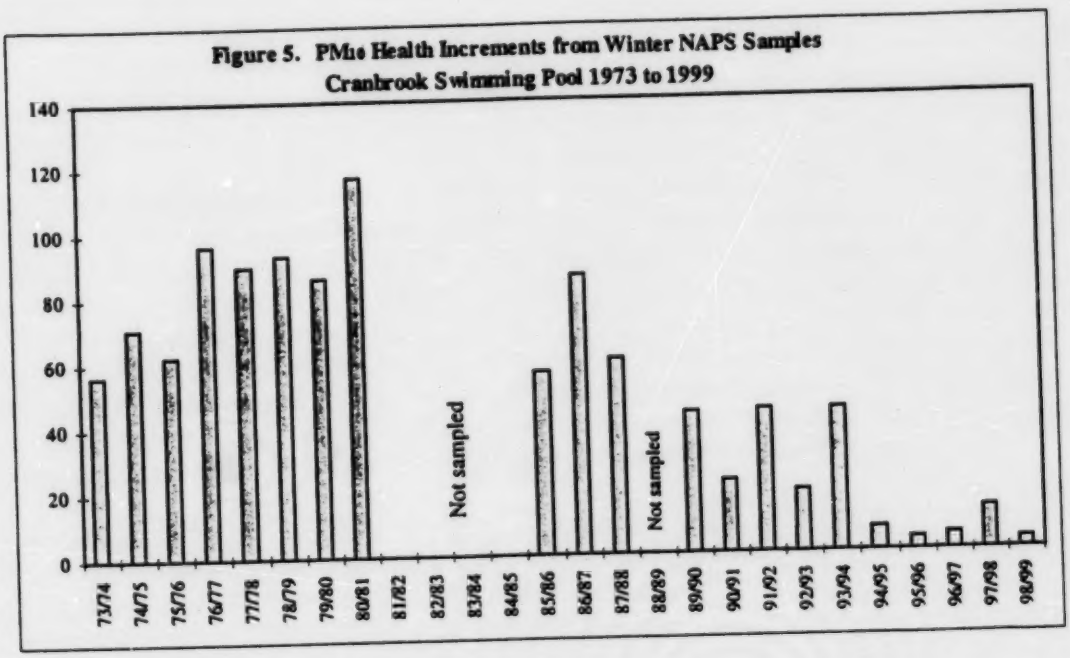
Figure 4. Percentage of Winter Samples at Cranbrook Swimming Pool Exceeding Air Quality Objectives
(Winter = November 1 to March 31)



36%). By the early 1990's, the number of excursions above 50 $\mu g/m^3$ had decreased further to 15 to 30% of winter samples, while the percentage exceeding 25 $\mu g/m^3$ was 42 to 68%. Winter FPM fell significantly in the winters of 1994/95 to 1998/99. Considering all five of these winters together, the 50 $\mu g/m^3$ provincial objective was only exceeded in 3 of 109 samples (2.7%), and the 25 $\mu g/m^3$ national reference level was exceeded in 29 samples (27%).

As a final method of evaluating the data in Appendix I the total number of human health increments (see Section 2) for each sample day have been calculated and totalled for each winter (Figure 5). It must be emphasized that Figure 5 does not represent the total number of health increments (or health risk) for each winter, which would require sampling every day, but includes only those on the NAPS sample schedule, approximately 25 out of the 150 days from November 1 to March 31. Figure 5 shows that the human health risk associated with breathing outdoor air in Cranbrook during the winter of 1997/98 (the last winter of complete sampling) was 90% lower than in the winter of 1980/81.

Figure 5. PM$_{10}$ Health Increments from Winter NAPS Samples Cranbrook Swimming Pool 1973 to 1999



One increment = each 10 µg/m^3 increase above 20 µg/m^3 (e.g. 33 µg/m^3 = 1 increment, 105 µg/m^3 = 8 increments). The number of winter increments = total of all NAPS day increments from Nov 1 to Mar 31. Each winter includes between 21 and 26 samples except 91/92 (19) and 98/99 (18).

In simple terms, the cause of the decline in winter PM_{10} in Cranbrook is either a change in winter atmospheric conditions towards better dispersion or a general reduction in source emissions over time. There has been no historical collection of meteorological data in Cranbrook, and global climate change notwithstanding, it is unlikely that atmospheric conditions have changed sufficiently to produce the magnitude of FPM reduction observed. A city-wide decrease in the amount of PM_{10} emitted during the winter is considered a more plausible explanation.

There is, unfortunately, little or no documented information quantifying changes in source emissions over this 26-year period. To relate emissions to ambient conditions we must rely largely on circumstantial and anecdotal evidence. For example, in the early 1970's a sawmill

burner operated at the south end of town (Figure 1). This was an older generation beehive burner with a poor emission (Poll. Prev. file CA02391) that undoubtedly contributed to winter PM_{10}. This burner, however, was permanently shut down in December 1974 with little apparent effect on average and maximum winter PM_{10} at the CSP (Figure 3). Another sawmill burner, located in the northwest, industrial part of the city, operated throughout the 1970's. In 1979 the old beehive burner was replaced with a newer model fitted with over and under fire fans and temperature-controlled dampers. Figure 3 and 4 show that the upgrading of this burner had little effect on PM_{10} levels at the CSP, which reached their highest levels in the winter of 80/81. The upgraded burner was permanently shut down in the summer of 1995, though PM_{10} levels appeared to drop significantly in the winter of 94/95 when the burner was still in operation.

The fact that changes in the operation of the sawmill burner do not match changes in ambient PM_{10} at the CSP is an indication that this particular industrial point source has not had a measurable influence on ambient fine particulate levels over the city.

Mobile air pollution sources (vehicles, train locomotives, aircraft, etc.) emit FPM and the gases (nitrous oxides, organic compounds, sulphur dioxide) that result in secondary particulate formation in the atmosphere (CEPA/FPAC Working Group 1999). Although modern internal combustion engines generally have cleaner emissions than 25 years ago, the total emission from these sources can be assumed to track population growth fairly closely. The population of Cranbrook has risen from 13,853 in 1976 to 19,598 in 1998 (BC Stats, 1998) a 41% increase, most of this growth occurring in the 1990's. If vehicle emissions in the City have increased in a similar fashion we can conclude that they have little influence on winter fine particulate levels measured at the CSP, which have trended in the opposite direction (downwards).

Years of monitoring and field observations have lead the author and other staff of the local Pollution Prevention office to conclude that residential wood burning has been the major source of winter fine particulate in Cranbrook (W. Kusy, L. Leinweber, and M. Strosher, personal communication). In the early 1980's the sight of chimneys emitting thick wood smoke was common in Cranbrook and in winter the hi-vol filters had a characteristic wood smoke or chimney smell. This conclusion is corroborated by the fact that the same phenomenon was observed in many communities in colder climates throughout the United States and Canada.

Around 1900 oil and natural gas began to replace coal and wood as home heating fuels, particularly so from 1940 until 1972 (Cooper 1980). Following the OPEC oil embargo in 1973 and the accompanying dramatic rise in the cost of furnace oil, wood again became a popular alternative fuel (Cooper 1980). In 1960 the number of domestic heating stoves shipped in the United States was about 590,000. This number steadily dropped each year to a low of 250,000 in 1972 and then rose sharply to 1 million by 1980 (Cooper 1980). The resurgence of wood space heating was accompanied by the development of the airtight wood stove, distinguished from open fireplaces or older wood burners by the ability to almost completely cut off the air supply to the fire. The early generation of airtight wood stoves had poor emission quality, especially when operated with the goal of making the fuel last as long as possible by dampening down the air supply. This may have been a thermally efficient use of the fuel but it greatly increased the emission of particulate matter, carbon monoxide and products of incomplete combustion.

Budiansky (1980) described this as a "perverse relationship: What's good for energy efficiency is not good for the environment". The use of wood for residential heating can generate 20 times more particulate material than furnace oil and 50 times more than natural gas, per unit of heat output (Rau 1989).

Missoula, Montana, located 350 km south of Cranbrook in similar mountainous terrain, suffered similar FPM problems during winter inversions in the 1970's and 1980's. Studies were conducted in Missoula to determine the relative contributions of various emissions (industrial, mobile, residential wood burning) to ambient particulate levels. These studies found that, in the winter, 54% of the TSP was attributable to residential wood burning (Church 1981). Since PM_{10} is a sub-set of TSP, excluding larger particles of road dust, wood stove emissions could be expected to have accounted for an even larger portion of ambient PM_{10} than 54%.

During the mid-1980's public concern about winter air quality in Cranbrook was significant, as evidenced by the large number of complaints and enquiries received by the Ministry of Environment and other agencies. Callers were often persons suffering from asthma or other chronic pulmonary ailments. The numbers of these complaints had fallen off significantly by the late 1990's.

In the early 1990's, in an attempt to reduce high levels of winter PM_{10} in Cranbrook, a program of public education and wood stove emission management was established cooperatively by the local Pollution Prevention office and the City of Cranbrook. The public was provided with information on the hazards of FPM, local air quality and optimal wood stove operation through the use of brochures, videos, contributed newspaper articles and staff interviews on radio and cable TV. During the winters of 1990/91 though 1992/93 City staff issued weekday PM_{10} air quality advisories to the public based on continuous PM_{10} monitoring at the CSP (see Section 3) and local weather forecasts. The advisories provided qualitative information on FPM air quality (good, fair, or poor) and recommended voluntary curtailment of wood stove use during poor conditions, unless it was the sole source of heat. Advisories were placed in local newspapers, radio and cable television and were also available on a phone-in hot line that also recorded caller comments. Though public interest and response was favourable the program was discontinued due to improving air quality.

Through the early 1990's large quantities of educational material on the health hazards of fine particulates and the efficient use of wood for home heating were produced by government and non-government groups. Examples of these brochures and guidebooks include:

- *Fine Particulates: What they are and how they affect us* and *Reducing Wood Stove Smoke: A Burning Issue* from BC Environment;
- *Reducing Wood Stove Smoke: A Burning Issue* from BC Environment;
- *Let's clear the air about wood stoves* from Environment Canada;
- *A Guide to Residential Wood Heating* from Energy, Mines and Resources Canada;
- *Home Heating with Wood: The Burning Question* from the B.C. Lung Association;
- Numerous operational brochures from the Canadian Wood Energy Institute and the Wood Energy Technicians of B.C.

Further measures at the provincial level to address the wood stove emission problem, being experienced in many B.C. communities, included the passing of the Solid Fuel Burning Domestic Appliance Regulation under the Waste Management Act. This regulation required that all new wood stoves sold after November 1, 1994 meet Canadian Standards Association emission standards. Other related legislation included the Open Burning Smoke Control Regulation, which came into effect in April 1993 and sought to ensure that the open burning of clearing and demolition debris occur during periods of proper atmospheric ventilation, and thereby limit human exposure to excessive quantities of smoke.

While the efforts to raise public awareness may have had some effect on the extent nature of wood stove use for home heating in Cranbrook, the main reason for the downward trend in winter PM_{10} levels is more likely the result of a switch from wood to natural gas appliances. Indeed, increased public awareness of the health hazards of FPM in outdoor air was probably a factor that encouraged people to make this conversion. Through the late 1980's and 1990's natural gas was comparatively inexpensive and viewed as cleaner and more convenient than wood heating. Sales of natural gas inserts and stoves through this period grew, which encouraged the gas utility to extend service into rural areas surrounding the city and to aggressively market natural gas appliances considerably (R. Colombo, BC Gas, personal communication).

4.3 Annual Fine Particulate Trends in the 1990's

Figure 6 is a graph of all NAPS PM_{10} samples, summer and winter, at the CSP from January 1992 through February 1999. For comparison, Figure 7 is a graph of all NAPS PM_{10} over the same period from Johnson Lake, a rural reference site located 45 km north of the Cranbrook, approximately in the middle of the Rocky Mountain Trench. This site is near no dwellings but is influenced by a nearby gravel pit, road dust, and occasional wildfires.

The horizontal line at 50 $\mu g/m^3$ on Figures 6 and 7 represents the current 24-hour PM_{10} air quality objective for B.C. In Cranbrook, over this 7 year period, 30 out of 423 samples (7%) exceeded this objective, compared with one sample (0.2%) at Johnson Lake. Again, it must be pointed out that these samples are taken every 6 days so this does not represent the total number of days in this period when the objective was exceeded. Since 1995, when PM_{10} levels in Cranbrook appeared to decrease relative to the previous few years (Figures 3,4,5 and 6), only 10 samples exceeded 50 $\mu g/m^3$, compared with 4 at Johnson Lake over the same period.

The horizontal line at 25 $\mu g/m^3$ on Figures 6 and 7 represents the National PM_{10} reference level (CEPA/FPAC 1998). Over this 7 year period 129 samples (30%) of the NAPS samples in Cranbrook exceeded this level, compared with 23 (5%) at Johnson Lake.

A comparison of annual average PM_{10} from the CSP site and Johnson Lake (Figure 8) further illustrates an improvement in FPM air quality in Cranbrook through the 1990's. The decrease in PM_{10} in Cranbrook from 1994 to 1995 is apparent in Figure 8, as it was in the previous graphs of

winter sampling (Figures 3, 4, and 5). From 1992 to 1994 a person living in Cranbrook was exposed to PM_{10} levels three times higher than those rural residents were exposed to. From 1995 to 1997 this fell to two times the exposure. The cause of the increase in annual average PM_{10}, seen at both sites in 1998 (Figure 8), is not known but an examination of Figures 6 and 7 indicates that the higher PM_{10} episodes occurred in the spring and summer.

Figure 6. PM_{10} at Cranbrook Swimming Pool 1992 - 1999
(Horizontal lines: 50 = BC Objective, 25 = National Reference Level)

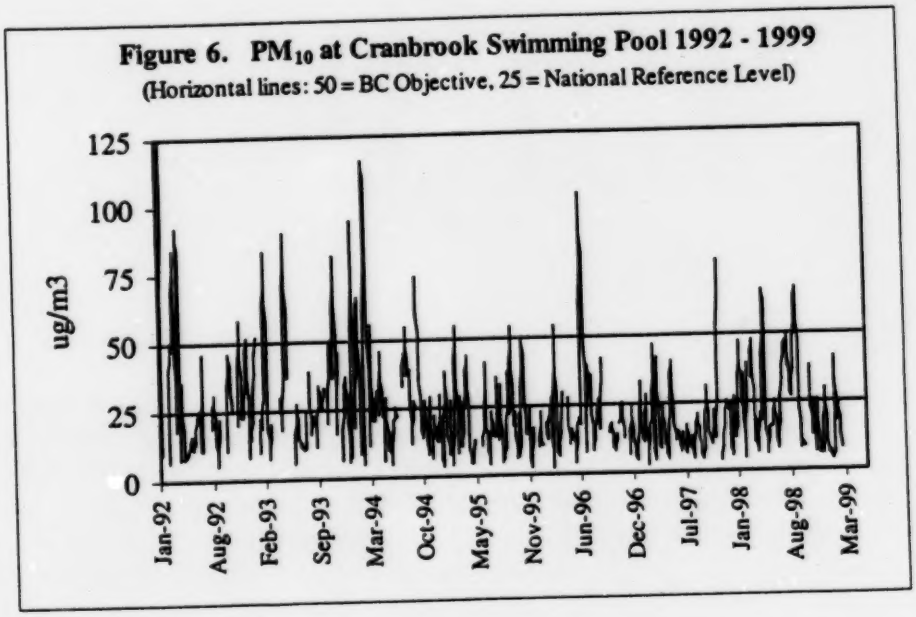


Figure 7. PM_{10} at Johnson Lake Reference Site 1992 - 1999
(Horizontal line: 50 = BC Objective, 25 = National Reference Level)

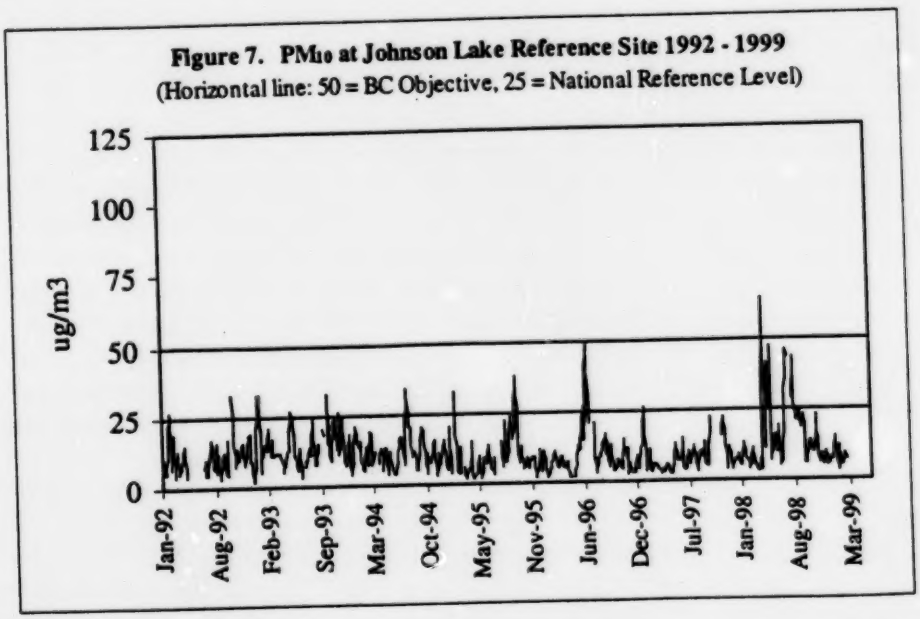
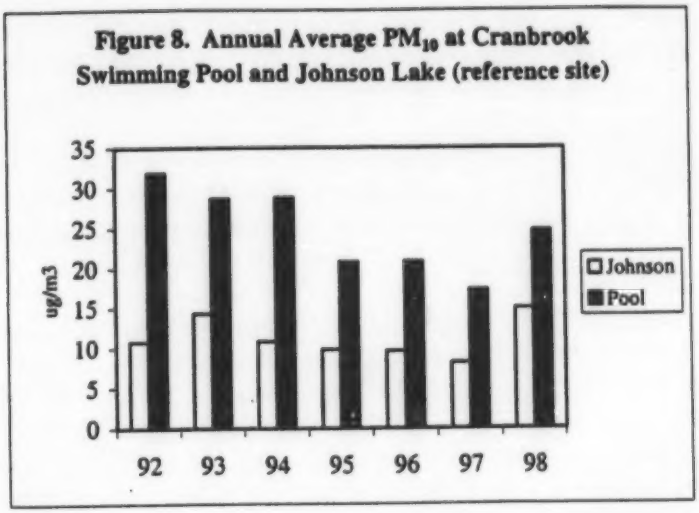


Figure 8. Annual Average PM_{10} at Cranbrook Swimming Pool and Johnson Lake (reference site)



5.0 Future Concerns

Average winter PM_{10} in Cranbrook in 1997/98, at the CSP, was 68% lower than they were in the winter of 1980/81 (Appendix I). In the two previous winters, 1995/96 and 1996/97, the average PM_{10} was 77% lower than 1980/81. The decrease in outdoor PM_{10}, described in this report, represents a significant reduction in health risk to the residents of Cranbrook. Unfortunately there is a real possibility that this trend may reverse itself and winter PM_{10} levels, originating from wood combustion for home heating, may increase.

A return to wood combustion for comfort heating is predicted because the cost of natural gas, for two decades the cheapest heating fuel, has risen dramatically. According to BC Gas Inc., in January 1998 the typical residential customer in the inland region paid $562/year (this cost often includes hot water heating). Following a series of price increases, the most recent in January 2001, this cost has risen to $1207/year, a 115% increase in two years (BC Gas Inc. 2000). The cause of this increase is the recent escalating demand from natural gas fired thermal electric power plants in the United States. Some 250 of these plants are under construction or have recently been completed to supply the fast growing U.S. economy, centered in California, which is dependent on digital equipment, computers and the Internet (Haines 2000, Reid 2001). The electric power demand for the Internet is reported to be doubling every three months (Haines 2000). Natural gas fired power plants are being favoured as more environmentally friendly than coal fired or nuclear plants or large hydroelectric dams (Reid 2001). The price of natural gas is predicted to continue to rise in the near future, despite the obvious market that now exists for increased gas production capacity (Reid 2001).

Under this heavy pricing pressure residential, commercial and industrial consumers of natural gas will increasingly turn to alternate fuels that will emit greater quantities of pollutants, including FPM. Though this shift to dirtier fuels will occur throughout the United States and Canada, air quality impacts will vary across the continent. Communities in mountainous terrain in colder climates will suffer disproportionately higher winter PM_{10} and associated human health

effects than those with better atmospheric dispersion characteristics. Smaller and medium sized towns in the northern Rocky Mountain States and British Columbia, where wood is still available, will be the first to experience higher winter PM_{10}.

Although a return to wood heating will result in increased emissions of FPM, air quality in communities like Cranbrook need not deteriorate to the levels experienced twenty years ago. When properly operated, modern wood stoves, characteristically wider than they are deep, have much lower particulate emissions than older models.

Unfortunately, it appears that the most important determinant of FPM air quality in Cranbrook, and similar communities, may be national and international energy policy, which determines the dominant home heating fuel. Over the past two years the response of these policies, or lack thereof, to rapidly changing energy markets has resulted in the huge increases in the price of natural gas, the cleanest burning heating fuel. Government and corporate policy makers must be cognisant of the impact on human health that will occur when a clean fuel like natural gas is no longer affordable for home and commercial heating and is supplanted by wood or coal. In the short term, to maintain good air quality, the individual homeowner must either absorb the increased costs of heating with natural gas or limit their wood stove emissions during conditions of poor atmospheric dispersion as best they can.

6.0 References

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APPENDIX I

WINTER TOTAL SUSPENDED PARTICULATE (TSP) AND PM_{10} AT THE CRANBROOK SWIMMING POOL, 1973/74 TO 1998/99

Appendix I. Winter TSP and PM_{10} at the Cranbrook Swimming Pool, 1973/74 to 1998/99

1973/74		1974/75		1975/76		1976/77		1977/78		1978/79		1979/80		1980/81	
TSP	PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}
36	28	324	228	8	8	116	84	147	105	29	23	138	99	68	50
44	34	76	56	21	18	161	115	79	58	73	54	152	109	135	97
57	43	60	45	15	13	85	62	45	34	44	34	117	84	99	72
37	29	25	20	132	95	142	102	57	43	192	136	335	236	35	27
37	29	184	131	30	24	26	21	53	40	72	53	83	61	35	27
25	20	70	52	32	25	36	28	60	45	76	56	27	22	14	13
180	128	37	29	36	28	144	103	33	26	84	61	61	45	150	107
58	43	55	41	23	19	7	8	22	18	110	79	72	53	41	31
81	59	14	13	60	45	10	10	93	68	139	100	119	86	157	112
7	8	39	30	24	20	61	45	69	51	36	28	123	88	123	88
64	47	31	25	130	93	107	77	23	19	65	48	47	36	187	133
28	22	16	14	24	20	47	36	25	20	26	21	59	44	53	40
19	16	37	29	40	31	49	37	22	18	52	39	46	35	119	86
222	157	43	33	44	34	22	18	34	27	39	30	88	64	100	72
19	16	24	20	90	66	91	66	45	34	29	23	78	57	7	8
19	16	55	41	277	196	147	105	32	25	233	165	17	15	68	50
19	16	16	14	30	24	45	34	35	27	15	13	64	47	235	166
34	27	172	123	21	18	44	34	75	55	81	59	33	26	81	59
94	68	52	39	10	10	179	127	49	37	197	140	20	17	326	230
111	80	142	102	26	21	164	117	201	143	49	37	19	16	148	106
162	116	103	75	50	38	83	61	265	187	323	228	27	22	128	92
83	61	62	46	102	74	42	32	120	86	70	52	25	20		
				165	118	80	59	226	160			79	58		
				73	54	121	87	178	127			76	56		
				98	71	109	79	77	56			86	63		
Number of Samples	22		22		25		25		25		22		25		21
Mean	48		55		46		62		60		67		58		79
Maximum	157		228		196		127		187		228		236		230
Minimum	8		13		8		8		18		13		15		8
No. of Samples >50 ug/m^3	7		7		8		14		11		12		13		15
No. of Samples >25 ug/m^3	15		16		14		21		21		18		19		19

Winter = November 1 to March 31.
*PM_{10} = data converted from TSP using formula: $PM_{10} = 0.6957(TSP) + 2.9102$ (see Section 4 for explanation)

Appendix I cont'd. Winter TSP and PM_{10} at the Cranbrook Swimming Pool, 1973/74 to 1998/99

1985/86		1986/87		1987/88		89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99
TSP	*PM_{10}	TSP	*PM_{10}	TSP	*PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}	PM_{10}
22	18	67	50	66	49	4	22	44	20	37	15	16	19	33	13
34	27	39	30	16	14	27	13	45	58	81	29	15	26	77	26
118	85	23	19	109	79	5	28	15	24	17	7	24	13	4	7
29	23	25	20	53	40	45	19	34	23	20	22	12	7	9	26
45	34	63	47	41	31	17	19	42	38	46	15	3	7	17	7
64	47	110	79	51	38	48	27	20	51	7	13	17	24	26	6
79	58	55	41	47	36	19	27	11	9	28	30	10	13	22	6
95	69	41	31	60	45	68	26	37	9	37	16	23	10	24	7
25	20	32	25	57	43	50	19	39	28	26	13	13	5	14	30
28	22	62	46	66	49	17	23	12	15	6	4	11	18	6	15
28	22	42	32	50	38	85	26	150	25	15	38	19	33	27	6
16	14	100	72	90	66	26	20	7	39	8	23	13	15	12	7
202	143	125	90	17	15	6	11	28	52	94	9	25	15	19	4
37	29	150	107	41	31	20	77	51	10	19	8	21	12	47	10
44	34	85	62	28	22	13	29	48	22	55	28	28	28	25	41
54	40	118	85	66	49	5	44	84	19	65	4	3	3	22	18
83	61	176	125	38	29	20	13	18	36	14	22	54	17	35	24
155	111	185	132	95	69	17	21	91	83	9	55	11	47	5	17
61	45	61	45	169	120	127	13	60	36	20	9	7	19	39	station
102	74	61	45	175	125	15	56		8	6	29	18	5	34	shut
63	47	112	81	51	38	68	13		20	115	20	30	42	47	down
82	60	99	72	85	62	52	22			101	11		12	11	
		98	71	115	83	68	15			12	19			22	
				34	27	75	114			55	29				
							29				44				
							53								
Number of Samples	22		23		24	24	26	19	21	24	25	21	22	23	18
Mean	49		61		50	37	30	44	30	37	20	18	18	25	15
Maximum	143		132		125	127	114	150	83	115	55	54	47	77	41
Minimum	14		19		14	4	11	7	8	6	4	3	3	4	4
No. of Samples >50 ug/m³	8		11		7	7	4	5	4	7	1	1	0	1	0
No. of Samples >25 ug/m³	16		21		21	12	12	13	9	12	8	3	5	9	4

Winter = November 1 to March 31.
*PM_{10} = data converted from TSP using formula: $PM_{10} = 0.6957(TSP) + 2.9102$ (see Section 4 for explanation).